

2

CONTRACT REQUIREMENTS	CONTRACT ITEM	MODEL	CONTRACT NO.	DATE
Exhibit E, Para. 5.5	18	LEM	NAS 9-1100	14 Jan'63

Type II Documentation

Primary Code 811

REPORT

NO. LTR 904-16001

DATE: 9-6-63

RESULTS OF LANDING GEAR

STABILITY DROP TESTS 1/6 SCALE MODEL

CODE 26512

F. Donroe
PREPARED BY:
F. DONROE

R. Sala
CHECKED BY:
R. SALA

R. Hilderman (for)
NOTED BY:
R. HILDERMAN & V. STURIALE

A. Whitaker
APPROVED BY:
A. WHITAKER

J. Gerardi for GCW
NOTED BY:
G. WIESINGER

REVISIONS

DATE	REV. BY	REVISIONS & ADDED PAGES	REMARKS

RESULTS OF LANDING GEAR STABILITY DROP TESTS1/6 SCALE MODELTABLE OF CONTENTS

<u>Item</u>	<u>Page</u>
List of Photographs -----	3
Introduction -----	4
Section A - 1/6 Scale Model - LTM320-10000	
1 Purpose -----	A-1
2 Description of Test Model -----	A-1
3 Test Set-Up and Procedure -----	A-1
4 Test Conditions -----	A-2
5 Discussion of Test Results -----	A-4
6 Summary of Test Results -----	A-5
7 Log of Tests -----	A-7
Figure I - Stability Profile Curve -----	A-9
Figure II - Acceleration - Time Curve -----	A-10
Figure III - Drop Test Fixture -----	A-11
Photographs -----	A-12

Code 26512 Eng-23A

Cont. NAS 9-1100
Prim. Code 811REPORT DATE LTR 904-16001
9-6-63

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

RESULTS OF LANDING GEAR STABILITY DROP TESTS1/6 SCALE MODELLIST OF PHOTOGRAPHS

<u>Title</u>	<u>Page</u>
Test Specimen -----	A-12
Pads Completely Restrained - Vertical Velocity Only - Series I -	A-13
Lead Pads Restrained - Combination Vertical Velocity and Horizontal Velocity - Series I -----	A-14
All Pads Restrained - Combination Vertical Velocity and Horizontal Velocity - Series I -----	A-15
All Pads Restrained - Series II -----	A-16
Modified Pad Fitting -----	A-17
Model Attach & Release Assembly -----	A-18

Code 26512 Eng-23A

Cont. NAS 9-1100
Prim. Code 811

REPORT
DATE

LTR 904-16001
9-6-63

RESULTS OF LANDING GEAR STABILITY DROP TESTS1/6 SCALE MODELINTRODUCTION

This report contains the results of all tests conducted with the LEM 1/6 Scale Model - LTM320-10000.

The report is presented in sections, the first of which, Section A, contains the results of the Preliminary Landing Gear Stability Drop Tests. Should it be necessary to conduct further tests on this type of model, the results of these tests will be included as additional sections to this report.

Code 26512 Eng-23A

Cont. NAS 9-1100
Prim. Code 811

REPORT LTR 904-16001
DATE 9-6-63

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

RESULTS OF LANDING GEAR STABILITY DROP TESTS 1/6 SCALE MODELSECTION A - 1/6 SCALE MODEL - LTM320-100001.0 Purpose

1.1 This section of the report contains the results of initial developmental tests which were performed to evaluate the stability of a proposed four-strut configuration of the LEM lunar landing gear. The test model used, (GAEC drawing no. LTM320-10000), was not an exact 1/6 scale LEM model because the LEM landing gear configuration has undergone substantial change since this model was made. Therefore, the data obtained as a result of these tests may serve only to verify analytical techniques for this particular model.

1.2 These tests were conducted in partial fulfillment of the requirements of Contract No. NAS 9-1100.

2.0 Description of Test Model

2.1 The test model was dimensionally a one-sixth scaled model of a proposed LEM vehicle having a landing gear tread radius of 141.4 in. The model weight was 45.5#, the C.G. was vertically located 26.2 inches above the pads, and the sprung mass moment of inertia was 5.35 slug-ft². The sprung mass is defined as the total mass of the model less the mass of the gear strut pistons and pad assemblies. The test specimen is shown on page 1.12.

2.2 In order to provide extremes in "friction" conditions the foot pads were modified as explained in Test Conditions and Discussion of Test Results. A typical modified pad may be seen in the photo on page 1.17.

3.0 Test Set-Up and Procedure

3.1 The test set-up and procedures were as described in the test plan Report No. LTP-560-1. The drop test set-up is shown in Figure III.

3.2 Model attach and release is accomplished through a pneumatically actuated clamp assembly. At model release the clamp assembly is triggered by a carbon filament circuit breaker when the drop test fixture is perpendicular to the ground. The attach and release assembly may be seen in the photograph on page A-18.

Code 26512 Eng-23A

TEST CONDITIONS

The tests consisted of two series and were conducted at ambient environmental conditions. Model landing gear orientation to direction of flight for all tests was two gears leading. Conditions for Series I and II are outlined below.

Series I

Vertical Vel. fps	Horizontal Vel. fps	Model Attitude	Impact Surface	Cartridge Load Level-lbs		Remarks
				Primary Struts	Secondary Struts	
10	0	Level	Lubricated Aluminum 0° Slope	244	140	Surface Condition Simulated: Minimum Friction.
13	0	"	"	"	"	
10	0	"	"	"	"	Legs wired together at pad fittings, chordwise and diagonally such that the radius at the pads could not change. See photo on page 1.13. Surface condition simulated: Four Holes.
15	0	"	"	"	"	
8	5	10° Nose-Up	"	"	"	Lateral motion of lead gears restrained by chordwise wire. Forward motion of specimen restrained at contact with surface by an obstacle. See photo on page 1.14. Surface condition simulated: Forward-shallow holes, aft-minimum friction.
8	6	"	"	"	"	
8	7	"	"	"	"	
8	5	"	"	"	"	Restraining wire removed. Forward motion of specimen restrained at contact with surface by an obstacle. Surface condition simulated: Forward-Protruberance (curb), Aft-minimum friction.
8	6	"	"	"	"	
8	7	"	"	"	"	
8	5	"	"	"	"	Lateral motion of lead gears restrained by chordwise wire. Forward motion of specimen restrained with an obstacle approximately 6 in. downrange from lead gear contact point. Surface condition simulated: Forward-Shallow holes, Forward & Aft-minimum friction.
8	6	"	"	"	"	
8	7	"	"	"	"	
8	5	"	Forward Gears- Lubricated Aluminum.	"	"	Lateral motion of lead gears restrained by a chordwise wire. Aft gears restrained at surface contact by a pad attachment with small prongs. Forward motion of specimen restrained at contact with surface by an obstacle. See photo on page 1.15. Surface condition simulated: Forward & Aft-shallow holes.
8	6	"	Aft Gears - Wood. 0° Slope	"	"	

TEST CONDITIONS

Series II

Vertical Vel. fps	Horizontal Vel. fps	Model Attitude	Impact Surface	Cartridge Load Level-lbs		Remarks
				Primary Struts	Secondary Struts	
12	Start at 2 fps and increase until instability occurs	- 5° Nose-Up	Wood 5° Down Slope	140	140	For all runs in this series the impact surface was to duplicate a restrained condition on all gears. The restraint was provided at the surface contact by pad attachments with small prongs. (See photograph on page 1.16). Surface condition simulated - shallow holes forward and aft.
10	Start at 2 fps and increase until instability occurs	"	"	"	"	
8	Start at 3 fps and increase until instability occurs	"	"	"	"	
6	Start at 4 fps and increase until instability occurs	"	"	"	"	
4	Start at 5 fps and increase until instability occurs	"	"	"	"	
2	Start at 6 fps and increase until instability occurs	"	"	"	"	

RESULTS OF LANDING GEAR STABILITY DROP TESTS 1/6 SCALE MODELSECTION A - 1/6 SCALE MODEL - LTM320-100004.0 Discussion of Test Results

- 4.1 Series I consisted of dropping the model with vertical velocity only and a combination of vertical and horizontal velocities. Other conditions imposed upon the model were as described in the chart of test conditions found on page A.2.
- 4.2 All combination drops in this series were made with a vertical velocity of 8 fps. All other conditions imposed upon the model were identical for all drops with the exception of the simulated landing surface. The effect of various surfaces upon the stability of the model may be found in the Summary of Test Results on page A-5.
- 4.3 In order to provide the maximum stroking condition upon the gear upper struts, a surface with the lowest coefficient of sliding friction was provided. The result of a coefficient of sliding friction investigation determined this to exist under the following conditions: a lubricated aluminum landing surface and lubricated rubber gear pads. The coefficient of sliding friction under these conditions was .096.
- 4.4 Series II consisted of dropping the model with a combination of vertical velocity and horizontal velocity. Other conditions imposed upon the model were as described in the chart of test conditions found on page A-3.
- 4.5 The stability profile for vertical velocities of 2 fps to 12 fps may be found in the Summary of Test Results, Series II, on page A-6 and Figure I.
- 4.6 Maximum vertical and horizontal accelerations for Series I and II may be found in the Summary of Test Results on pages A-5 and A-6. A typical acceleration-time curve is shown in figure II.
- 4.7 As a result of measuring the energy absorption cartridges before and after each drop it was possible to determine the amount of kinetic energy absorbed by the cartridges. By determining the amount of kinetic energy for each drop at impact and comparing this value with the energy absorbed by the cartridges after completion of the drop it has been determined that the cartridges were absorbing 15 - 20% less energy than that which existed at model impact. This unaccountable energy is dissipated in several ways. Venting air from the struts, rebounding of the model, piercing of the wood impact surface by the spiked pads, stretching of the restraining cables and surface friction.

Code 26512 Eng-23A

Cont. NAS 9-1100
Prim. Code 811REPORT LTR 904-16001
DATE 9-6-63

SUMMARY OF TEST RESULTS

Drop No.	Vert. Vel. (fps)	Hor. Vel. (fps)	Model Attitude	Impact Surface	Cartridge Load Level-lbs		Condition	Maximum Vertical Accel. (g's)	Maximum Horizontal Accel. (g's)	Results
					Primary Struts	Secondary Struts				
7	10	0	Level	Lubricated Aluminum 0° Slope	244#	140#		18.6		
8	13	0	"	"	"	"		22.9		
26	10	0	"	"	"	"	Pads completely Restrained	29.6		
27	15	0	"	"	"	"	"	33.0		
13	8	5	10° Nose Up	"	"	"	Lead Pads Restrained	15.0	16.5	Stable
22	8	6	"	"	"	"	"	14.2	17.0	Unstable
18	8	7	"	"	"	"	"	13.2	16.5	Unstable
9	8	5	"	"	"	"	Lead Pads Restrained By a curb	10.0	12.4	Stable
23	8	6	"	"	"	"	"	9.6	11.6	Unstable
19	8	7	"	"	"	"	"	11.2	15.8	Unstable
14	8	5	"	"	"	"	Slide-Lead Pads Restrained	14.0	17.25	Stable
20	8	6	"	"	"	"	"	9.4	13.8	Stable
16	8	7	"	"	"	"	"	8.8	11.5	Unstable
28	8	5	"	Forward gears- Lubricated Aluminum.	"	"	All Pads Restrained	11.8	15.12	Stable
29	8	6	"	Aft gears-Wood 0° Slope	"	"	"	8.8	12.9	Unstable

SUMMARY OF TEST RESULTS

Series II

Drop No.	Vert. Vel. (fps)	Hor. Vel (fps)	Model Attitude	Impact Surface	Cartridge Load Level-lbs		Test Condition	Maximum Vertical Accel. (g's)	Maximum Horizontal Accel. (g's)	Results
					Primary Struts	Secondary Struts				
74	12	3.7	5° Nose Up	Wood 5° Down Slope	140	140	All Pads Restrained Upon Surface Impact, by Spiked Pads	10.0	15.1	Stable
76	12	4.2	"	"	"	"	"	11.0	15.4	Unstable
46	10	3.5	"	"	"	"	"	8.2	14.6	Stable
45	10	4.3	"	"	"	"	"	10.6	10.2	Unstable
53	8	5.2	"	"	"	"	"	7.5	11.0	Stable
52	8	5.8	"	"	"	"	"	6.4	11.8	Unstable
56	6	6.3	"	"	"	"	"	7.0	12.0	Stable
57	6	6.6	"	"	"	"	"	6.8	12.0	Unstable
61	4	6.9	"	"	"	"	"	6.2	11.6	Stable
62	4	7.35	"	"	"	"	"	8.4	11.6	Unstable
69	2	7.0	"	"	"	"	"	6.7	6.0	Stable
70	2	7.75	"	"	"	"	"	6.4	7.4	Unstable

RESULTS OF PRELIMINARY LANDING GEAR STABILITY DROP TESTS 1/6 SCALE MODEL

SECTION A - 1/6 SCALE MODEL - LTM320-10000

1.7		LOG OF TESTS			
DATE	RUN	VERT. VEL. FPS	HOR. VEL. FPS	CONDITIONS	REMARKS
4-29-63		11.1	0	Specimen Attitude-Level Cartridges: Primary Strut- 244#, Secondary Strut-140#	Check Drop
4-29-63	1	4	0	"	Greased Aluminum Landing Surface
4-30-63	2	8	0	"	" " " "
4-30-63	3	9.8	0	"	Oiled Aluminum Landing Surface
4-30-63	4	9.8	0	"	Greased Aluminum Landing Surface
5-1-63	5	13	0	"	" " " "
5-1-63	6	8	0	Specimen Attitude-10° Nose down	" " " "
5-13-63	7	10	0	Specimen Attitude-Level	" " " "
5-13-63	8	13	0	" " " "	" " " "
5-13-63		8	5	" " " "	Check Drop
5-17-63	9	8	5	Specimen Attitude-10° Nose Up, Lead Gears Restrained by Curb	Greased Aluminum Landing Surface
5-17-63	10	8	5	Lead Gears Restrained Fully	Left front pad jumped over obstacle
	11	8	5	" " " "	Pads engaged top of obstacle
	12	8	5	" " " "	" " " " " "
5-20-63	13	8	5	" " " "	" " " " " "
	14	8	7	Slide-restrained	
5-21-63	15	8	7	" " " "	Aft pads pulled out of uniball fitting on impact.
5-22-63	16	8	7	" " " "	
	17	8	7	Lead Gears Restrained by Curb	No photos
5-24-63	18	8	7	" " " "	Pads engaged top of obstacle
	19	8	7	" " " "	
	20	8	6	Slide-restrained	
	21	8	6	Lead Gears Restrained Fully	No photos
5-27-63	22	8	6	" " " "	
	23	8	6	Lead Gears Restrained by Curb	
5-27-63	24	8	6	Lead Gears Restrained by Curb	Soft cartridge investigation
5-29-63	25	10	0	Specimen Attitude Level	
6-2-63	26	10	0	All Gears Fully Restrained	
	27	15	0	" " " "	
6-4-63	28	8	5	" " " "	
6-5-63	29	8	6	" " " "	End of Series I
6-20-63	30	10	2	Specimen Attitude-5° Nose Up Lunar Surface-5° Down	Start Series II
				All Gears Fully Restrained	
				Cartridges-140# Load Level	
	31	10	3	"	
	32	10	4	"	
6-21-63	33	10	5	"	
	34	10	6	"	
	35	10	6	"	
6-24-63	36	10	4	"	
6-25-63	37	10	5	"	
	38	10	6	"	
6-26-63	39	10	6	"	
	40	10	6	"	Rear Gear Impact Surface made of Balsa Wood
6-27-63	41	10	5	"	
	42	10	6	"	
	43	10	6	"	Rotation of Rear Pads Restricted Allowing Pads to Impact Flat
	44	10	5	"	
6-28-63	45	10	4.3	"	
	46	10	3.5	"	
7-2-63	47	8	3	"	
7-2-63	48	8	4	"	
	49	8	5	"	
	50	8	5	"	
	51	8	6	"	
	52	8	5.8	"	
7-3-63	53	8	5.2	"	
	54	6	4	"	
	55	6	5.5	"	
7-8-63	56	6	6.3	"	No photos
7-9-63	57	6	6.6	"	
	58	6	6.5	"	Investigation-Solid Secondary Rear Struts
7-16-63	59	4	5	"	
	60	4	6	"	
	61	4	6.9	"	

RESULTS OF PRELIMINARY LANDING GEAR STABILITY DROP TESTS 1/6 SCALE MODEL

SECTION A - 1/6 SCALE MODEL - LTM320-10000

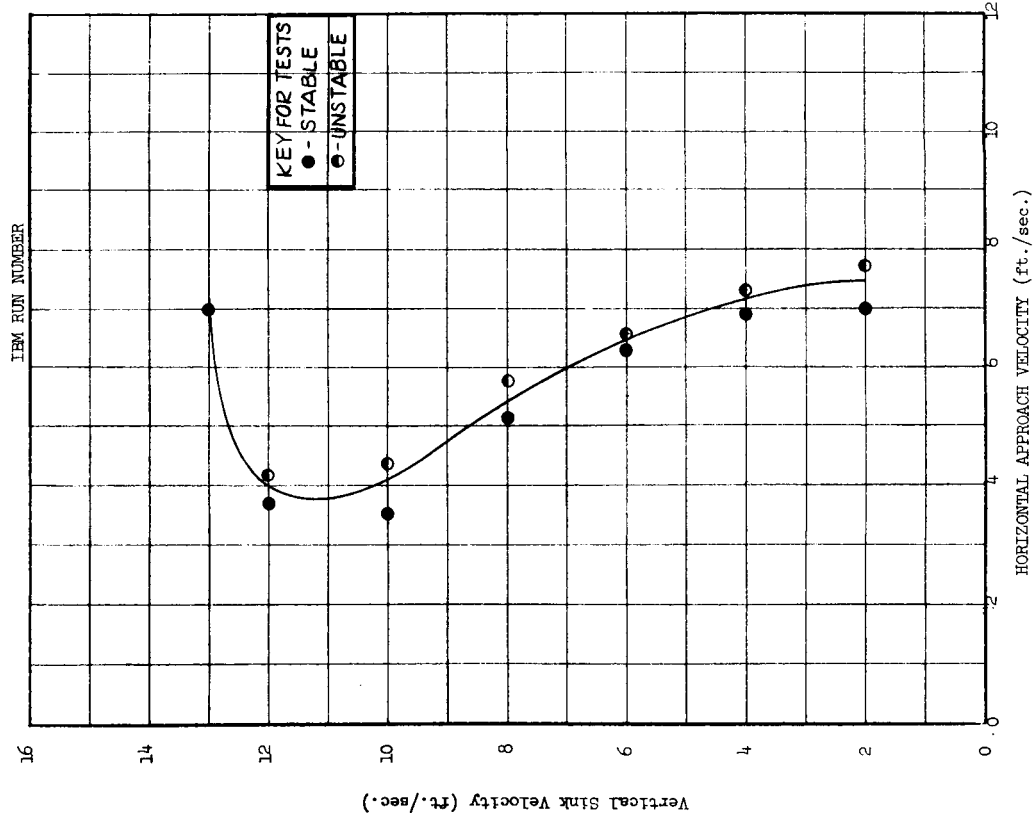
LOG OF TESTS - continued

DATE	RUN	VERT. VEL. FPS	HOR. VEL FPS	CONDITIONS	REMARKS
7-17-63	62	4	7.35	Specimen Attitude-5° Nose Up Lunar Surface-5° Down	
	63	2	6	All Gears Fully Restrained	
	64	2	7	Cartridges-140# Load Level	
	65	2	7	"	Missed Raised Surface
	66	2	6	"	
	67	2	6.5	"	
7/18-63				"	
	68	2	7	"	
	69	2	7	"	
	70	2	7.75	"	
7-22-63	71	12	2	"	
	72	12	2.5	"	
	73	12	3	"	
	74	12	3.7	"	
7-23-63	75	12	3.3	"	
	76	12	4.2	"	
7-23-63	77	13	3	"	
	78	13	4	"	
	79	13	5	"	
7-24-63	80	13	6	"	
8-6-63	81	13	6.5	"	
8-7-63	82	13	6.5	"	
	83	13	7.0	"	

Some Cartridges crushed fully
End Series II

Report LTR 904-16001
Date 9-6-63

LEM LANDING STABILITY STUDY (SERIES II) STABILITY-PROFILE CURVE



Basic Module Data
Weight 39.37 LBS
Pitch Moment of Inertia 5.35 S-FI²
C.G. Height above Pads 26.2 IN.
Semi Tread Radius 23.56 IN.
C.G. Eccentricity 0

Gear Data
Unsprung Mass 6.13 LBS
Coulomb Damping Forc. ~

*Primary Member:

$F_{CR} = 140 \text{ LB}$

$C = \sim$

$K_1 = \sim$

$K_2 = 0$

Secondary Members:

$F_{CR} = 140 \text{ LB}$

$C = \sim$

$K_1 = \sim$

$K_2 = 0$

Lunar Surface

Slope -5°

Surface-Pad Spring Rate \sim

Coefficient of Restitution \sim

Friction Coefficients \sim

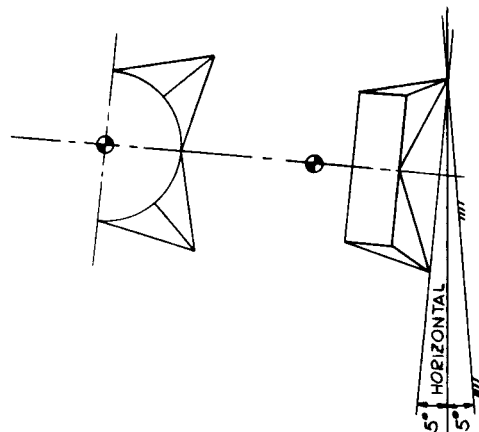
Initial Conditions

Pitch Attitude 5°

Pitch Rate 0

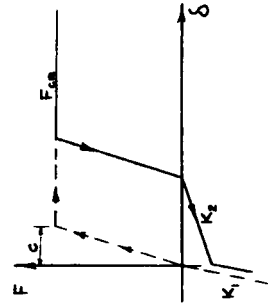
Comments:

CONSTRAINT IS OBTAINED BY EMPLOYING A SPIKED PAD.

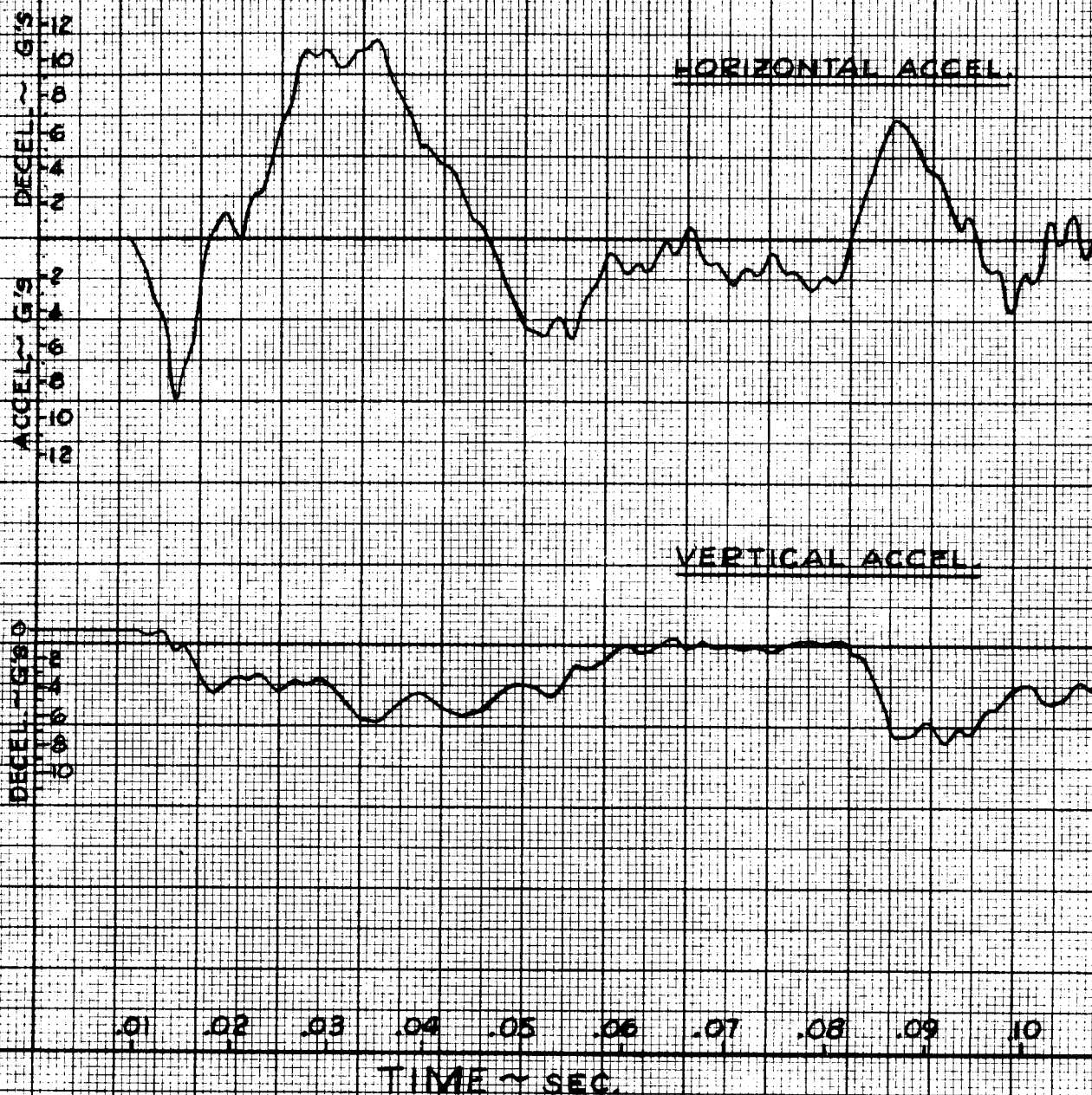


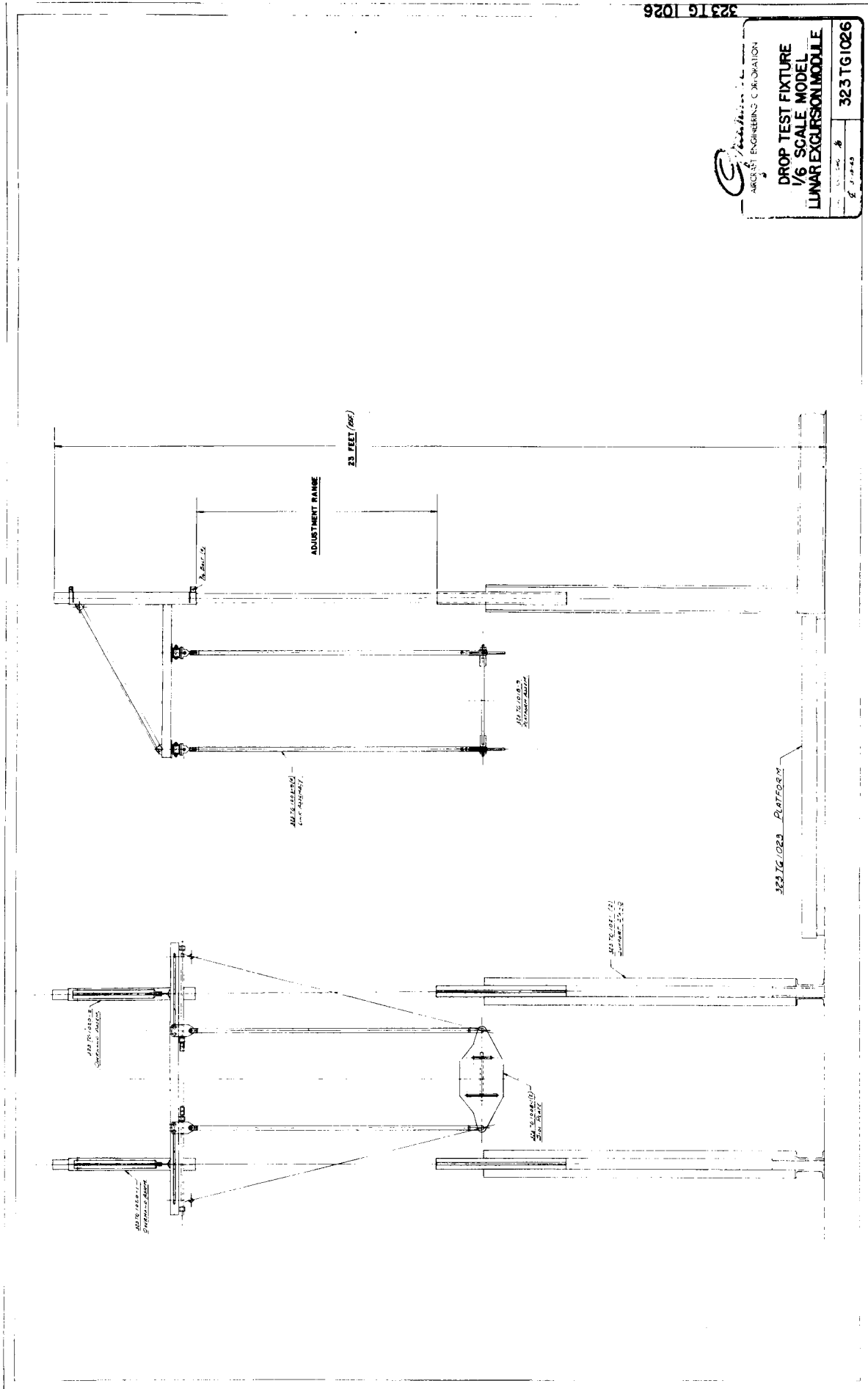
NOTE: ALL GEARS ARE RESTRAINED UPON SURFACE CONTACT.

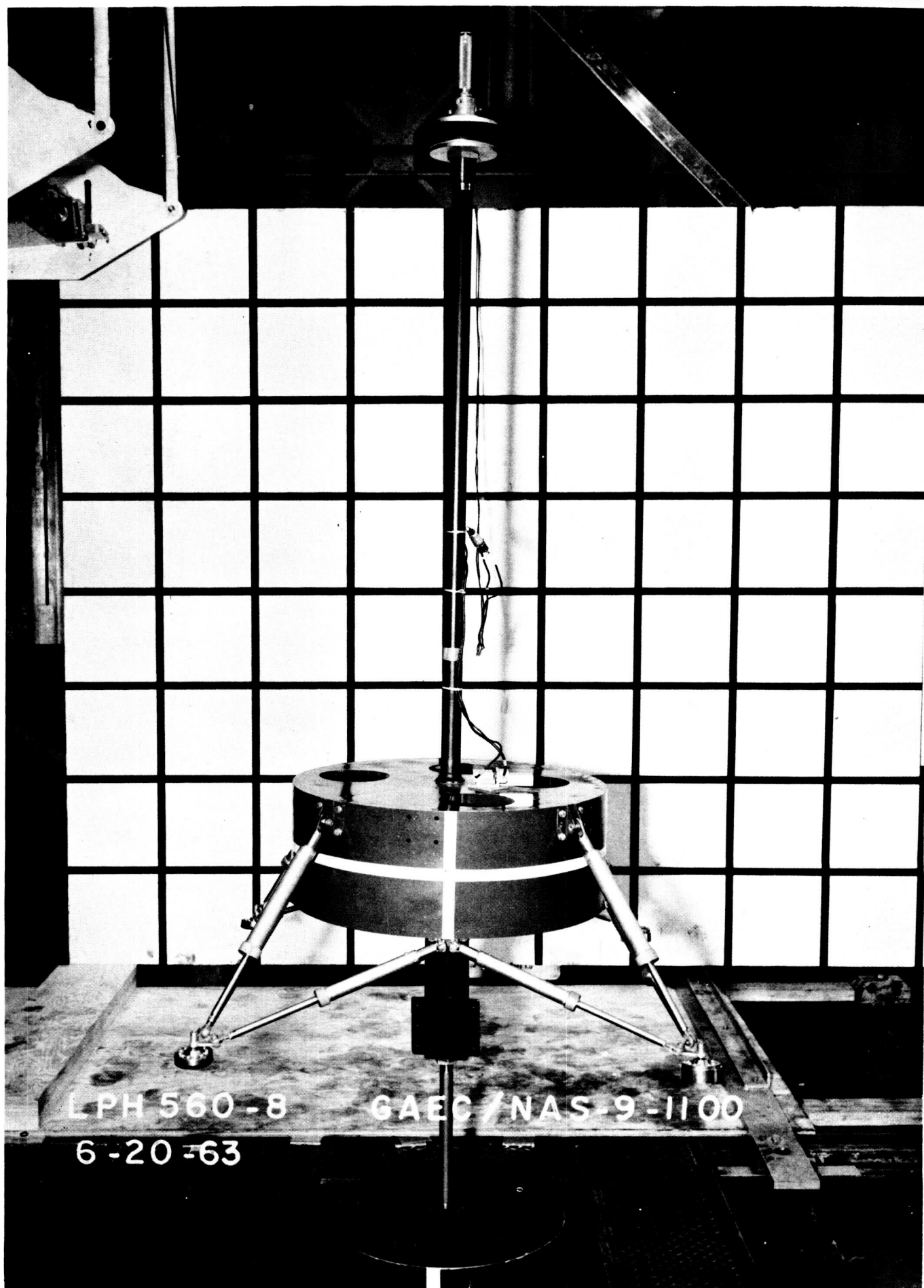
Sketch Showing Landing Configuration



* Load-Stroke Diagram for a Typical Strut

1/6 SCALE LEM MODEL (LTM 320-10000)DROP TESTDROP NO. 53AFT GEARS: FULLY RESTRAINED
LEAD GEARS: FULLY RESTRAINED4 GEAR CONFIGURATIONVERT. VEL. 8 FPSHOR. VEL. 5.2 FPSSPECIMEN ATTITUDE:5° NOSE UPLANDING SURFACE: 5° DOWNFIGURE II

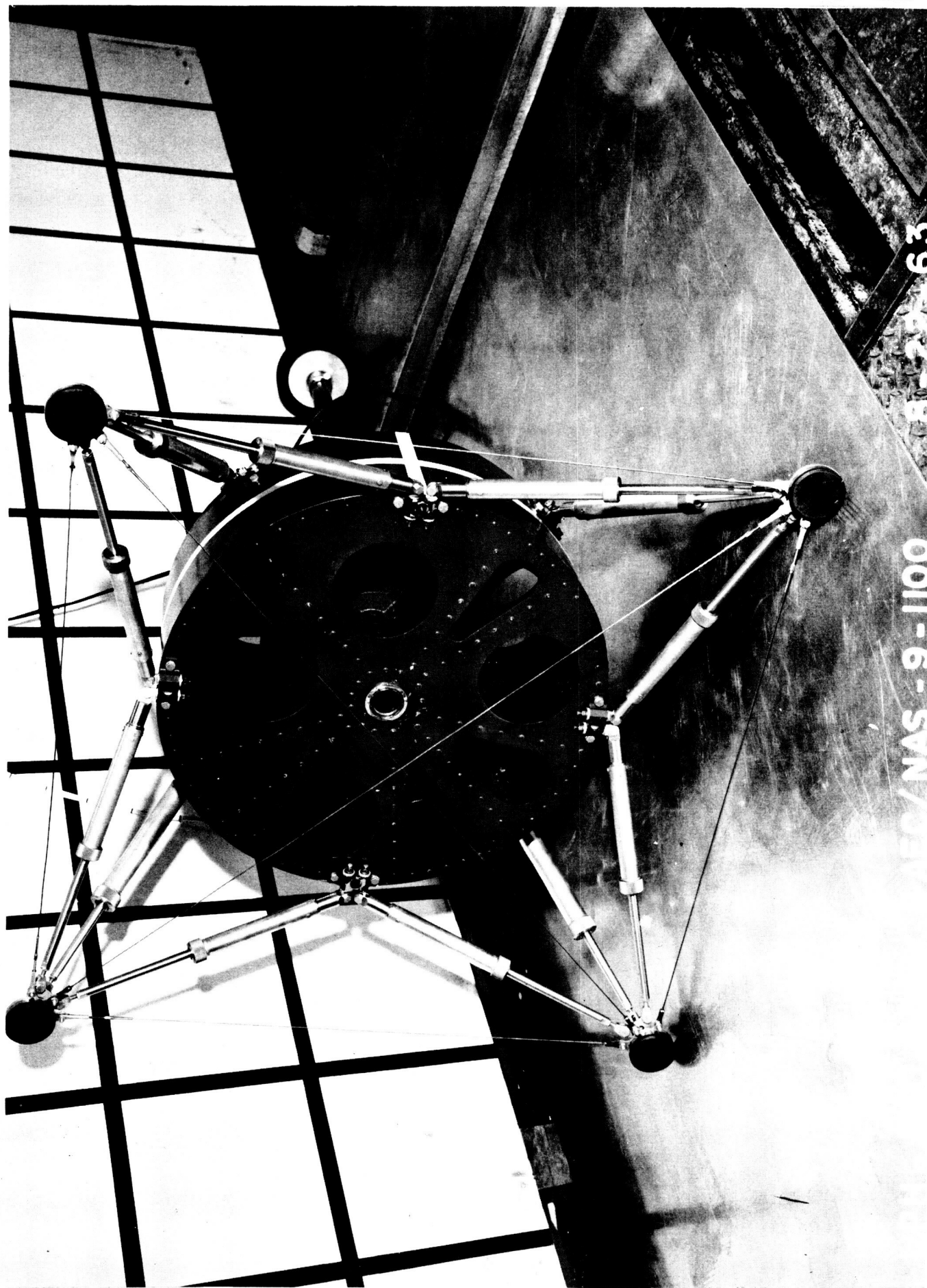




Test Specimen

Model LEM
Cont. NAS-9-1100
Prim. Code 811

Report LTR-904-16001
Date 9-6-63

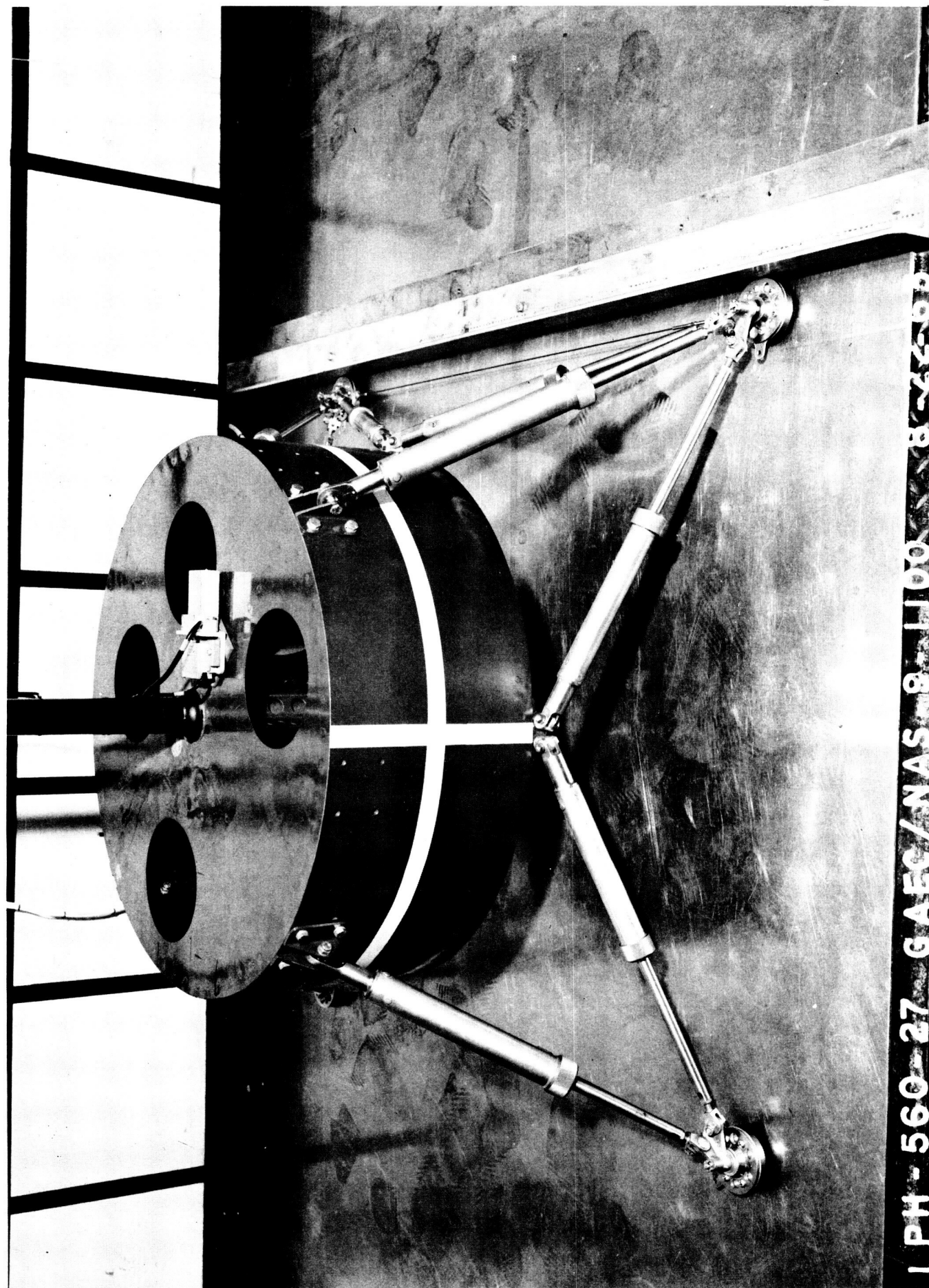


REC/NAS-9-1100 63

Pads Completely Restrained - Vertical Velocity Only - Series I

Model LEM
Cont. NAS-9-1100
Prim. Code 811

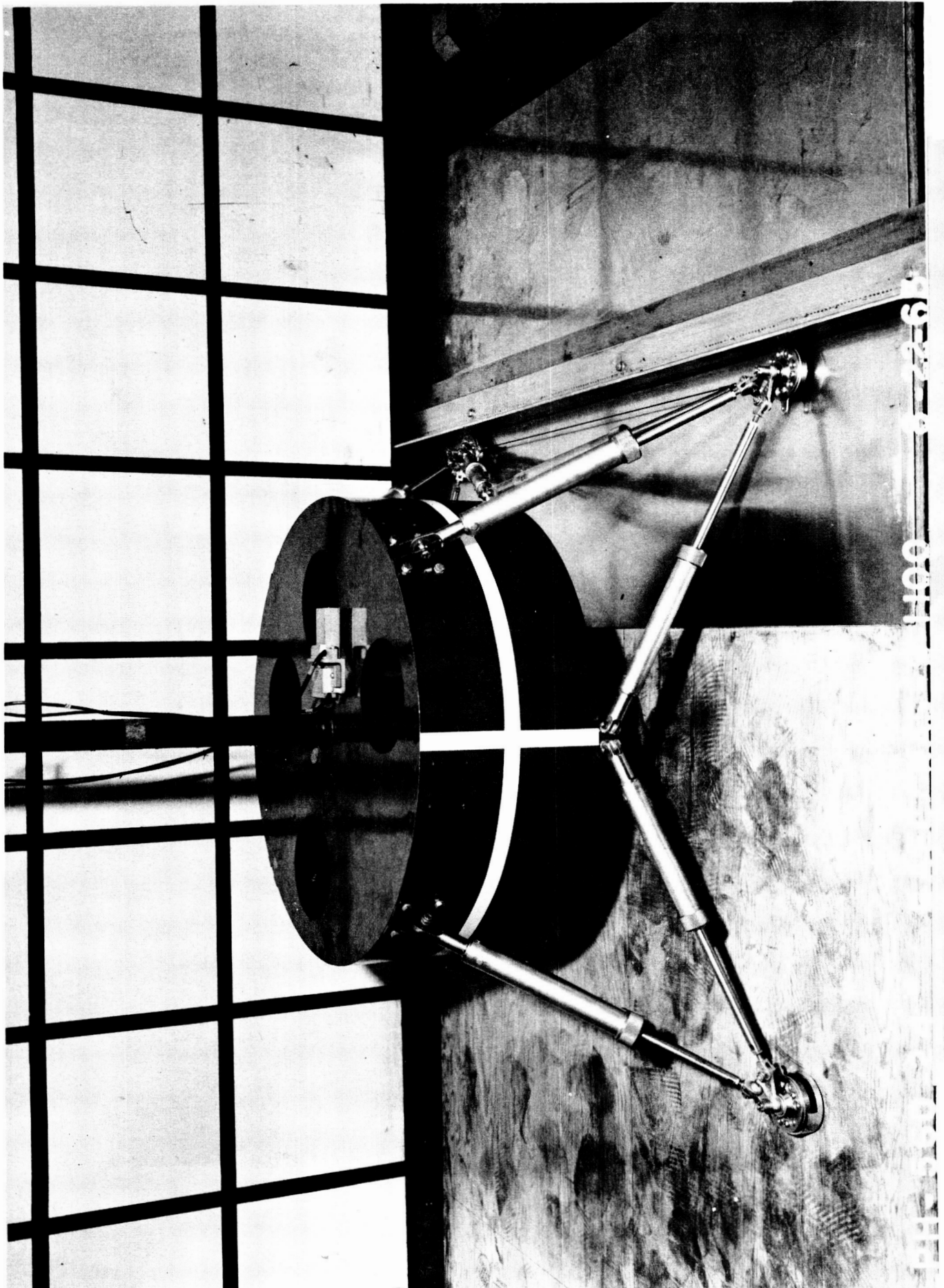
Report LTR-904-16001
Date 9-6-63



Lead Pads Restrained-Combination Vertical Velocity and Horizontal Velocity-Series I

Model LEM
Cont. NAS-9-1100
Prim. Code 811

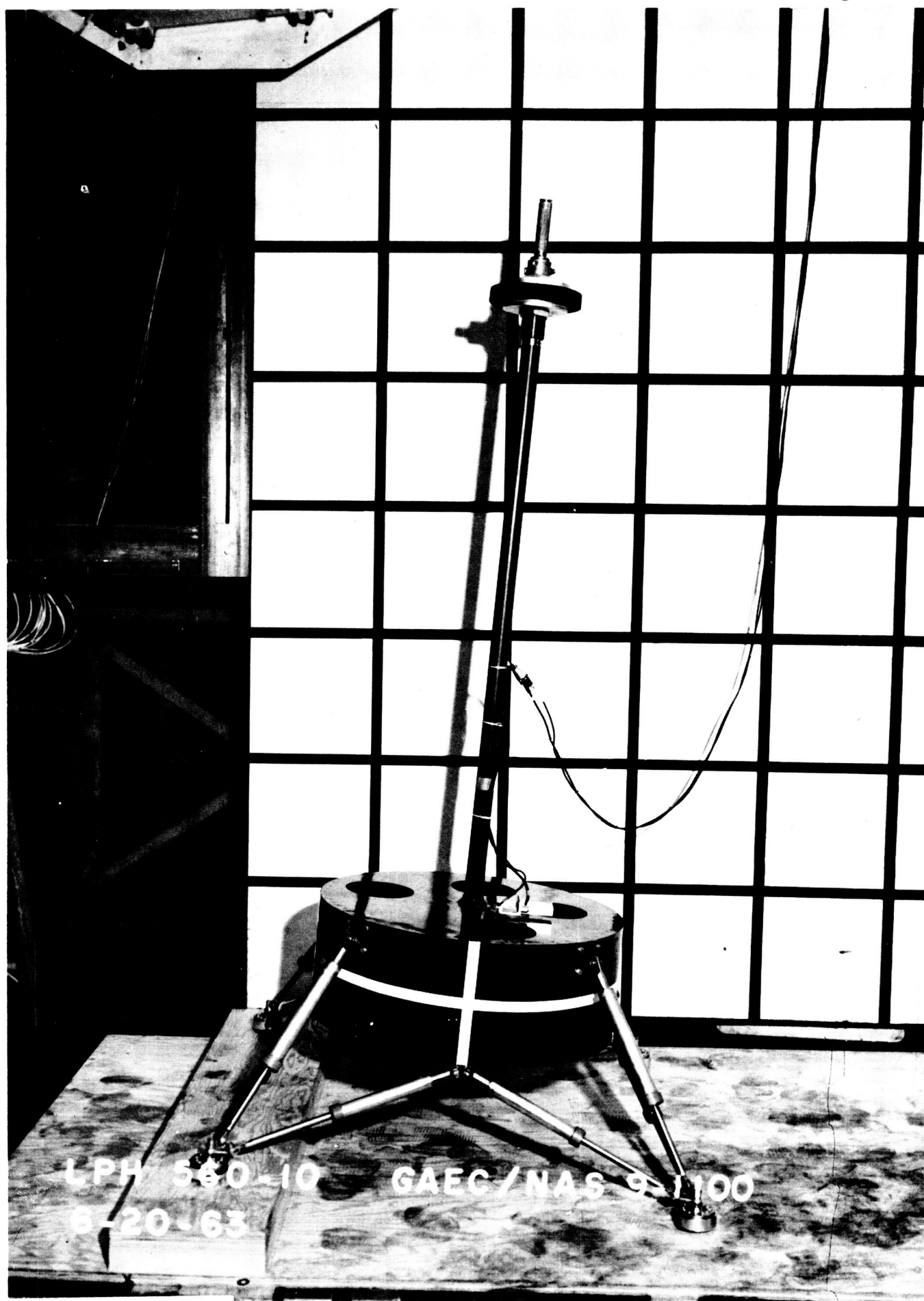
Report LTR-904-16001
Date 9-6-63



All Pads Restrained-Combination Vertical Velocity and Horizontal Velocity-Series I

Model LEM
Cont. NAS-9-1100
Prim. Code 811

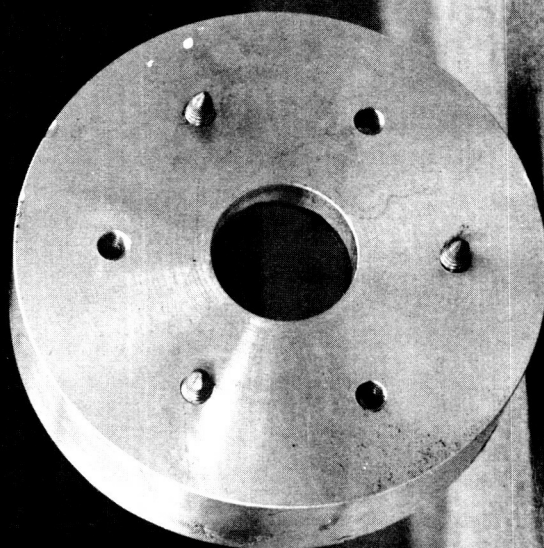
Report LTR-904-16001
Date 9-6-63



All Pads Restrained-Series II

Model LEM
Cont. NAS-9-1100
Prim. Code 811

Report LTR-904-16001
Date 9-6-63



Model LEM
Cont. NAS-9-1100
Prim. Code 811

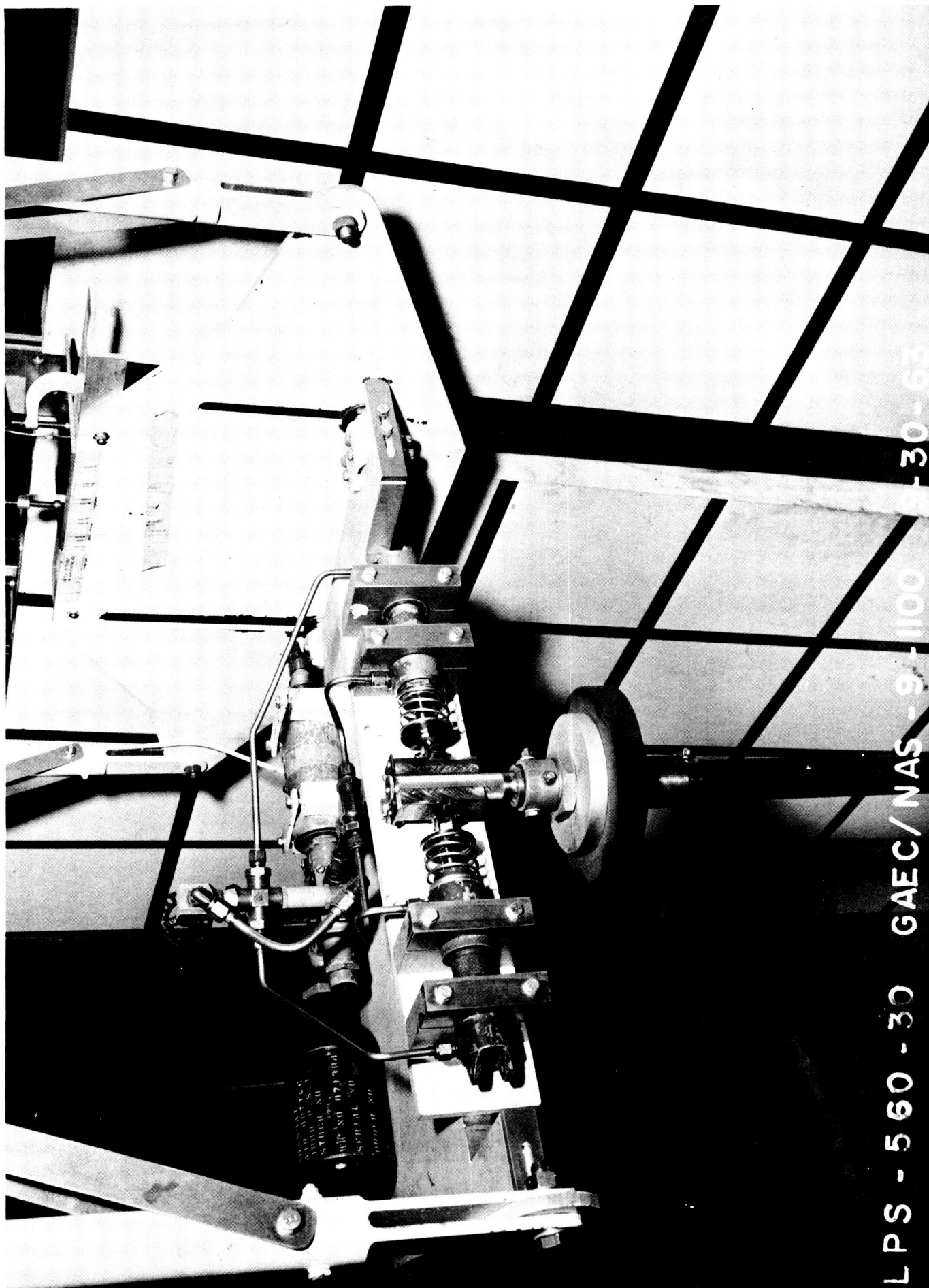
Report LTR-904-16001
Date 9-6-63

8-22-63

NAS-9-1100

GAEC/NAS-25

Modified Pad Fitting



Release Device

Model LEM
 Cont. NAS 9-1100
 Prim. Code 811

Report LTR-904-16001
 Date 9-6-63